ASSESSING CONSTRUCTION AND DEMOLITION WASTE ON MASONRY WORKS TO AVOID FUTURE GENERATION

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ABSTRACT

The difficulty of dealing with construction and demolition waste (CDW) on construction sites is not new and continues to be a significant environmental problem. Currently the CDW collection system in Spain is done in a decentralized manner by each sub-contracted company, being necessary to implement effective waste management measures ensuring a correct management and minimization.

During the last years several measures have been launched in order to improve and encourage the reuse and recycling of CDW. A widespread solution for CDW recovery is using them as a landscaping aggregate or for road bases and sub-bases. However, measures encouraging onsite prevention still need to be enhanced.

This paper studies the major work stage generating CDW and analyses the categories of CDW produced during its execution. For this, several real building sites have been analysed in order to quantify the estimation of CDW generated. Results of this study show that a significant contributor to the CDW generation on building construction sites in Spain are the masonry works.

Finally, a Best Practices Manual (BPM) is proposed containing several strategies on masonry works aimed not only at CDW prevention, but also at improving their management and minimization. The use of this BPM together with the Study and Plan of CDW management --required by law--, promotes the environmental management of the company, favouring the cohesion of the construction process organization at all stages giving rise to establishing responsibilities in the field of waste and providing a greater control over the process.

Keywords: construction and demolition waste, management, masonry works, good practice measures, prevention.

1.- Introduction

In recent years, Spain has generated 40 million tons of construction and demolition waste (CDW) causing harmful environmental impacts. In order to improve this situation appears the Royal Decree 105/2008, which regulates the production and management of the CDW, providing several new features in the Spanish regulations regarding waste [1]. Of special interest is the obligation to develop a Waste Management Plan and Report for each construction project. These Waste Management Plans encourage the minimization of avoidable waste, as well as recycling unavoidable waste, promoting the reduction of the environmental impact of the building construction activity.

Despite the high potential for recovery of CDW [2] and the existence of several management models (professionals, construction companies, software ...) today's professionals are still prioritizing the elimination of waste instead of recycling. According to the II National Plan of CDW for the period 2007-2015, data shows that the percentage of CDW recycled in Spain is lower than 18% of total CDW generated [3]. This situation comes from the waste collection system used in building construction, as it is done in a decentralized manner by each sub-contracted company [4]. This means that the principle of reducing waste is not applied in practice, it is not considered as an activity in the planning of the construction work.

In general, the construction sector is not familiar with the amount of waste generated in a construction project, or how it should be managed. The CDW planning usually carried out by construction companies has been limited to the estimation of the total amount of waste generated, and only a few go further and classify the CDW according to the construction activity. In addition, the same management system is used for all of the projects, without taking into consideration the characteristics of each building in particular. This situation could be solved in many cases, by planning in advance the quantity and types of CDW that will be generated [5].

In short, there is a significant lack of planning and implementation measures that minimize waste and encourage recycling waste generated in Spain. The development and use of specific indicators or ratios of CDW generation will help to know in advance the type of waste and the moment in which it will be generated. These ratios are useful and needed information to design and achieve an efficient waste management plan in a specific building construction. In addition, preventive planning measures are crucial to state a CDW management model whose primary goal is zero waste generation.

2.- Previous research studies on CDW management

The concern to establish indicators and parameters describing the waste generated by the construction activity has increased in recent years [6]. A variety of authors have developed new methodologies to quantify the CDW produced in both, new construction and demolition works. There have been several studies distinguishing the percentage for each waste category from the total generated (Table 1).

In particular, in Spain, Mañà i Reixach et al. study developed the percentages used by the Instituto Tecnológico de la Construcción de Cataluña (ITeC) to quantify five different categories of CDW generated according to the different construction systems [7]. Subsequently, in 2001 the I National Plan of CDW extends the information by providing data on a total of 12 different categories of CDW [8]. More recently, Mercader Moyano et al. (2011) obtained percentages for each waste category analyzing ten newly built residential buildings [11].

<table>
<tr><th rowspan="2">Waste</th><th></th><th colspan="5">Author/Source</th></tr>
<tr><th>Maña i Reixach et al. 2000</th><th>I PNIR 2001</th><th>Costa & Ursella 2003</th><th>Bergsdal et al. 2007</th><th>Mercader Moyano et al. (2011)</th><th>Llatas Oliver et al. (2010)</th></tr>
<tr><td>Soil and rocks not containing hazardous substances</td><td>-</td><td>9.00</td><td>-</td><td>-</td><td>-</td><td>67.00</td></tr>
<tr><td>Concrete</td><td>-</td><td>12.00</td><td>-</td><td>-</td><td>1.5</td><td rowspan="13">33.00</td></tr>
<tr><td>Bricks, tiles and ceramic materials</td><td>-</td><td>54.00</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Mixture of concrete, bricks, tiles and ceramic materials without hazardous materials,</td><td>85.00</td><td>-</td><td>84.30</td><td>67.24</td><td>-</td></tr>
<tr><td>Mixed CDW with no Mercury, hazardous materials or PCB</td><td>-</td><td>75.00</td><td>-</td><td>-</td><td>0.08</td></tr>
<tr><td>Timber</td><td>11.20</td><td>4.00</td><td>-</td><td>14.58</td><td>84.41</td></tr>
<tr><td>Paper & cardboard packaging</td><td>-</td><td>0.30</td><td>-</td><td>-</td><td>9.76</td></tr>
<tr><td>Plastic</td><td>0.20</td><td>1.50</td><td>-</td><td>-</td><td>0.73</td></tr>
<tr><td>Plaster</td><td>-</td><td>0.20</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Glass</td><td>-</td><td>0.50</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Metals</td><td>1.80</td><td>2.50</td><td>0.08</td><td>3.63</td><td>1.23</td></tr>
<tr><td>Asphalt</td><td>-</td><td>5.00</td><td>6.90</td><td>-</td><td>-</td></tr>
<tr><td>Other</td><td>1.80</td><td>11.00</td><td>8.80</td><td>14.55</td><td></td></tr>
<tr><td>Total</td><td>100</td><td>100</td><td>100</td><td>100</td><td></td><td>100</td></tr>
</table>

Table 1. “Percentage of each waste category from the total generated”. [7-12]

Other studies establish ratios for CDW generation --relating the quantities of waste generated and the built surface-- in building works (Table 2). Among them it is worth mentioning the analysis done by Bossink *et al*. [11] in 1996 establishing the first estimation of CDW generation in a study of 184 houses built in the Netherlands. Mañà i Reixach et al. developed the method used by the ITEC to quantify the waste generated per m^2 of built surface, according to the different construction systems [7].

Kofowoeola *et al*. study carried out in Thailand (2009) estimates the CDW in a general way. The information obtained from building permits issued showed a waste generation of 21.38 kg/m^2 for residential construction and 18.99 kg/m^2 for non-residential construction [13].

In 2010, the study conducted by Solis-Guzman et al. (2010) establishes a model for quantification of CDW based on the project budgets [14]. The model quantifies the different categories of waste generated, distinguishing the waste from the demolition, during the construction and from the packaging.

More recently, Llatas (2011) determined CDW generation ratios for three different categories: waste, packaging and soil. The results of the study identified the following generation ratios: 0.0569 m^3/ m^2built for the waste, 0.0819 m^3/ m^2built for packaging and 0.2805 m^3/ m^2built for land.

Finally, Table 2 shows the CDW generation ratios obtained in previous studies.

	II PNRCD	Maña i Reixach et al.		Kofoworola et al.	Solis-Guzmán et al.	Llatas
Country Year	Spain 2008	Spain 2000		Thailand 2009	Spain 2009	Spain 2011
Concrete	-	3.29	4.47	-	-	-
Bricks	-	-	-	-	-	-
Tiles and ceramic materials	-	-	-	-	-	-
Mixture of concrete, bricks, tiles and ceramic materials	-	96.92	96.92	-	-	-
Timber	-	2.52	0.99	-	-	-
Glass	-	-	-	-	-	-
Plastic	-	0.14	0.15	-	-	-
Mixed metals	-	3.38	3.93	-	-	-
Insulation materials	-	-	-	-	-	-
Plaster	-	5.93	5.93	-	-	-
Mixed CDW	-	0.87	0.87	-	-	-
Total	120	114.3	114.5	21.38	255.49	115.29

Table 2. “CDW generation ratios obtained in previous studies for newly built residential constructions (kg/m^2)”.

3.- Aim

The main objective of this paper is the definition of effective indicators which allow quantifying, not only the total waste generated in the construction site and in each activity, but also the different categories produced in the activity generating more CDW. These indicators or ratios intend not only to improve existing management systems, but also assist the construction agents responsible for the management of CDW to develop the waste management plans according to the existing legislation, and therefore, contribute to achieve the quantitative targets set for 2015 in Spain. [3]

4.- Methodology

The research has focused on obtaining data from five real projects carried out by the company ARPADA S.A, with similar construction features, including materials and techniques.

Project	First Certification	Situation	Nº dwelings	floor área per dweling (m^2)	Total floor área (m^2)	Constructive Techniques
O156	Jun-10	Getafe	156	119	30.759,68	Reinforced concrete structure. Flat roof. Brick façade, thermal insulation and interior partition of plasterboard.
O154	Ene-10	Getafe	154	112	25.936,00	Reinforced concrete structure. Flat roof. Brick façade, thermal insulation and interior partition of plasterboard.
O115	Jul-09	Móstoles	105	115	20.435,24	Reinforced concrete structure.

Project	First Certification	Situation	Nº dwelings	floor área per dweling (m^2)	Total floor área (m^2)	Constructive Techniques
						Flat roof. Brick façade, thermal insulation and interior brick partition wall.
O32A	Jun-10	PAU Vallecas	32	111	5.983,46	Reinforced concrete structure. Flat roof. Brick façade, thermal insulation and large format brick partition wall.
O32B	Jun-10	PAU Vallecas	32	111	5.983,46	Reinforced concrete structure. Flat roof. Brick façade, thermal insulation and large format brick partition wall.

Tabla 3. “Characteristics of the selected projects”.

Moreover, an experimental analysis has drawn information obtained from: (1) on-site delivery notes of the containers, (2) delivery notes issued by the CDW manager once weighed the container in its plant and (3) the dates of the following construction certifications:

- First certification of the project. (Initial month)
- Last certification of structure. Including: previous works, earthworks, drainage, foundation and structure.
- First and last certification of masonry. Including: exterior walls, thermal insulation, interior partitions, holes, chases, and plastering.
- First certification of finishes I: when tiling starts. Includes: tiling, flooring, paving ceiling, external glazing, etc.
- First certification of finishes II: when painting starts. Includes: painting, flooring, baseboards, wood doors, decorating, gardening, urban furniture, etc.
- Last certification of the project. (Last month)

An example of how the data is obtained for each construction project can be seen in Table 4.

Information of waste containers					CDW generation according to the construction activity		
Nº	Price €	Type of CDW	Weight (kg)	Volume(m^3)	Activity	Total kg	Total m^3
					Total CDW per activity		

Table 4. “Example of data collection in the experimental analysis”.

The experimental study --using real on-site data-- identifies the activity generating more waste. For this, the histograms’ methodology developed in the research work of the Solar Serrano et al. (2010) has been used [16].

However, the data collected from the experimental study is limited, because the CDW quantities are obtained for mixed CDW without considering waste categories (plastic, timber, etc.). Therefore, it is necessary to perform a theoretical analysis to obtain detailed information of the categories of waste generated.

For the theoretical analysis, the Archimedes Cype Software (2012) has been used, together with measurements, to quantify in weight (kg) the different waste categories generated in each activity and in the entire building construction. The theoretical analysis has been performed for the three projects built with brick interior partition walls. In addition, materials defined in the European Waste List as the category 170504 "*soil and stones not containing hazardous substances*" has been excluded, as it is not considered as waste in the Directive 2008/98/CE [17].

The last stage of this research included the establishment of several indicators relating the waste generated volume (m^3) and the total built surface of the building (m^2). If any of the values is null, the arithmetic mean does not apply, and the mean of the values different from cero is used instead.
Finally, the ratios have been obtained relating the waste generated in weight and the total built surface (m^2).

5. Results and discussion

The CDW quantification obtained from the delivery notes of five projects analysed, together with the theoretical analysis, allows for a first approach to obtaining a ratio relating the weight of the waste generated and built area. Thus, we obtain three ratios estimating: the overall weight of the CDW generated, the waste generated in each activity and the waste categories generated in the activity generating more waste.

5.1.- Quantification of the total CDW generated in the entire construction work

The first indicator (i_1) (table 5) is reached, relating the total CDW volume generated (m^3) in the construction work and the built surface (m^2). From the data obtained of the five construction projects, an average indicator ($í_{1m}$) is obtained, allowing for an estimation --in building constructions with the same characteristics as the ones studied-- of the total waste generated once the built surface of the project is known.

Project	Total built surface (m^2)	kg CDW	$í_1$ kg CDW/m^2built	Interior partition wall	MEAN $í_{1m}$ kg CDW/m^2built
O156	30759.68	2934829.00	95.41	Plasterboard	90.55
O154	25936.00	2222305.00	85.68	Plasterboard	
O 105	20435.24	2370680	116.01	Brick	132.69
O 32A	5983.46	978392	163.52	Brick	
O 32B	5983.46	709220	118.53	Brick	

Tabla 5. "Relationship between total CDW generated in the construction work and the built surface (Indicador $í_1$)".

Results from Table 5 show that, larger construction projects having plasterboard partition walls have smaller ratios, meaning they generate less CDW per m^2 of built surface.

This indicator is widely used by professionals to know the approximate generation of the total waste produced, once the total built surface is known. Figure 1 shows a comparison between the indicators obtained in this study and those obtained by other researchers in previous studies (Table 2).

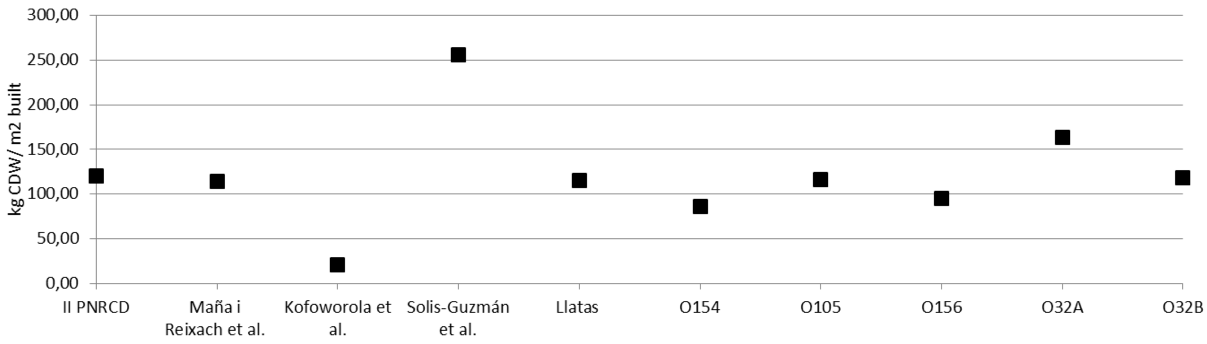


Fig. 1. “Comparison between the ratios obtained in this study and those obtained in previous studies”.

The differences among the various sources can be due to the following factors:

- The different construction systems used in the houses analysed by the different authors (type of facade, structure, foundations…)
- The built surface considered in the study (it depends on whether the common areas of the buildings have been considered, either totally or partially).

5.2. - Quantification of CDW regarding the construction activities

It is important to know, not only the total amount of waste to be generated, but also the stage or activity in which it is going to be generated. Thus, in works with similar characteristics, masonry and finishing’s activities generate about 20% of the total CDW to be generated (fig. 2).

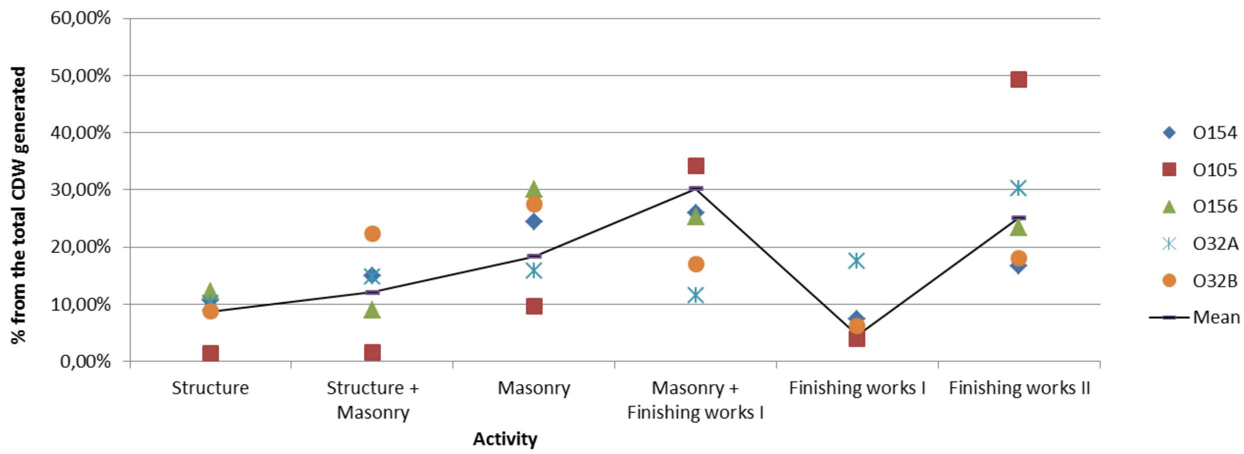


Fig.2 “Percentage of total CDW weight generated at each construction activity”.

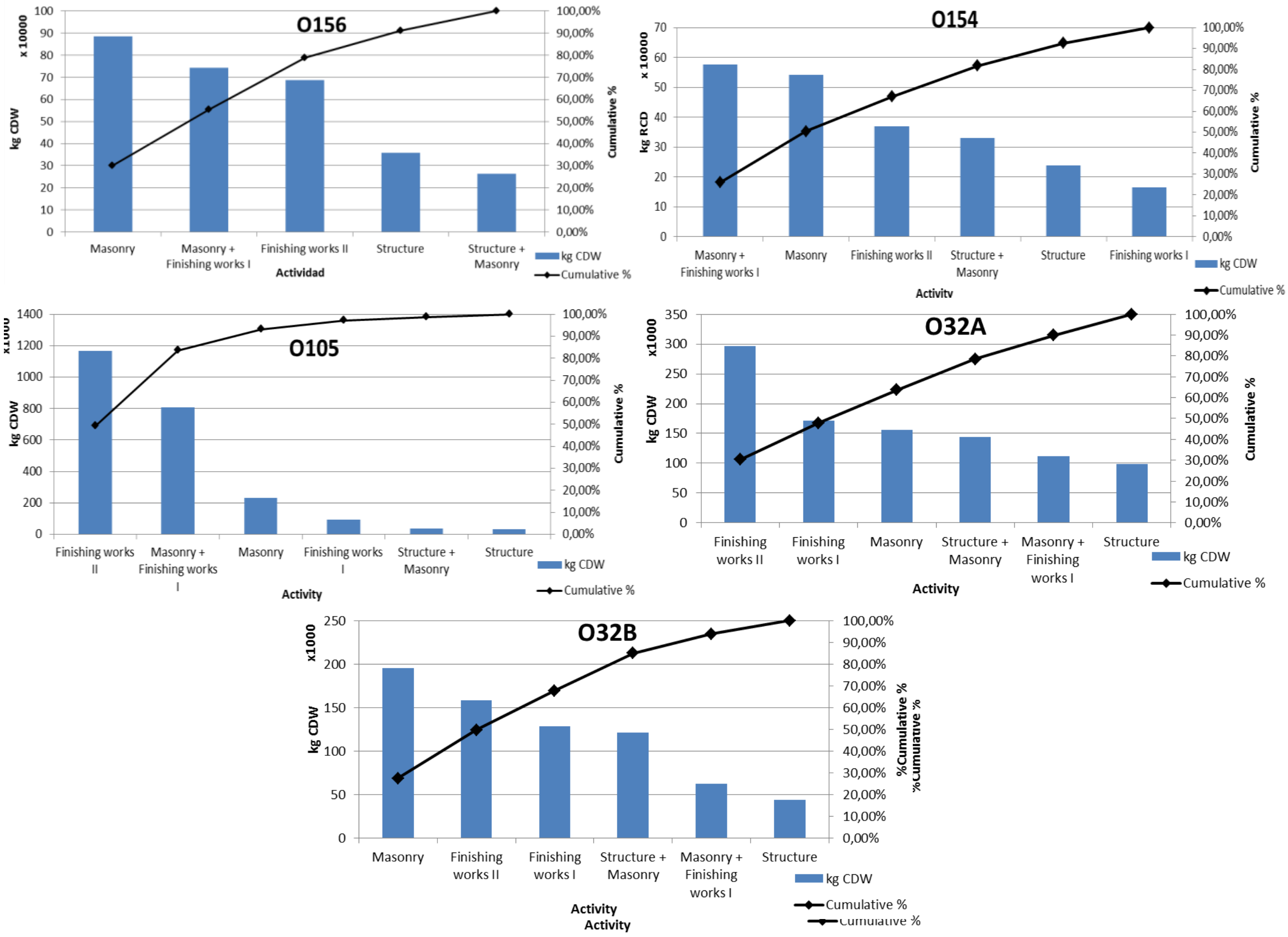


Fig. 3. "CDW quantification for each construction activity (in weigh)".

Moreover, relating these quantities (fig. 3) with the total built surface (m^2) a second ratio is established ($\acute{\imath}_2$). This will provide information of CDW quantification regarding each construction activity, obtaining detailed CDW information (table 6 & fig. 4).

Construction activity	**O154**	**O105**	**O156**	**O32A**	**O32B**	**Mean $\acute{\imath}_2$** (kg CDW/m^2built)
Structure	9.20	1.66	11.66	16.55	7.37	9.28
Structure + Masonry	12.75	1.84	8.53	24.10	20.27	13.50
Masonry	20.87	11.25	28.74	25.96	32.59	23.88
Masonry + Finishings I	22.26	39.57	24.12	18.72	10.46	23.03
Finishings I	6.38	4.51	-	28.66	21.44	15.25
Finishings II	14.22	57.17	22.36	49.52	26.41	33.94

Table 6. "Relationship between total CDW generated in each construction activity and the total built surface (indicator $\acute{\imath}_2$)".

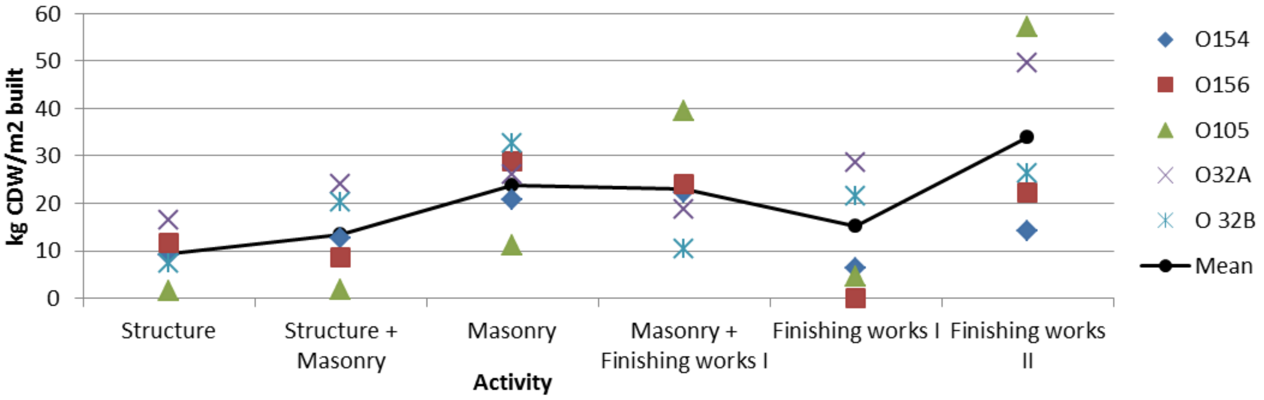


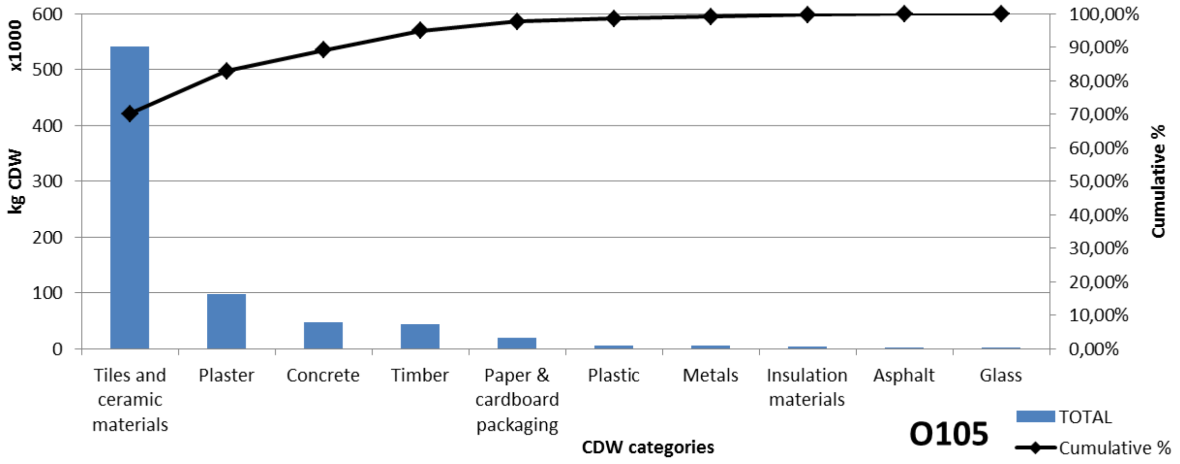
Fig. 4. “Ratios of CDW generation for each construction activity”.

Few references have been found regarding indicators in relation to construction activities. Among them, Maña i Reich study [7] determines --for conventional buildings-- an indicator for three construction units: structure, masonry and finishings. This study concludes that it is masonry the one that generates the greatest amount of CDW (0,05 m^3_{CDW}/m^2_{built}).

5.2. - Quantification of RCD generated in masonry and finishing works

In order to plan a better CDW management it is necessary, not only to know the indicator estimating the global generation of produced waste, but also to supply an indicator which estimates the generation of each of the CDW types separately and individually during the masonry and finishing works.

From the analysis of the projects with brick partition walls (O105, O32A, O32B) results show that the waste from brick and ceramic materials, plaster and timber account for around 90% of total generation in weight (Fig. 5).



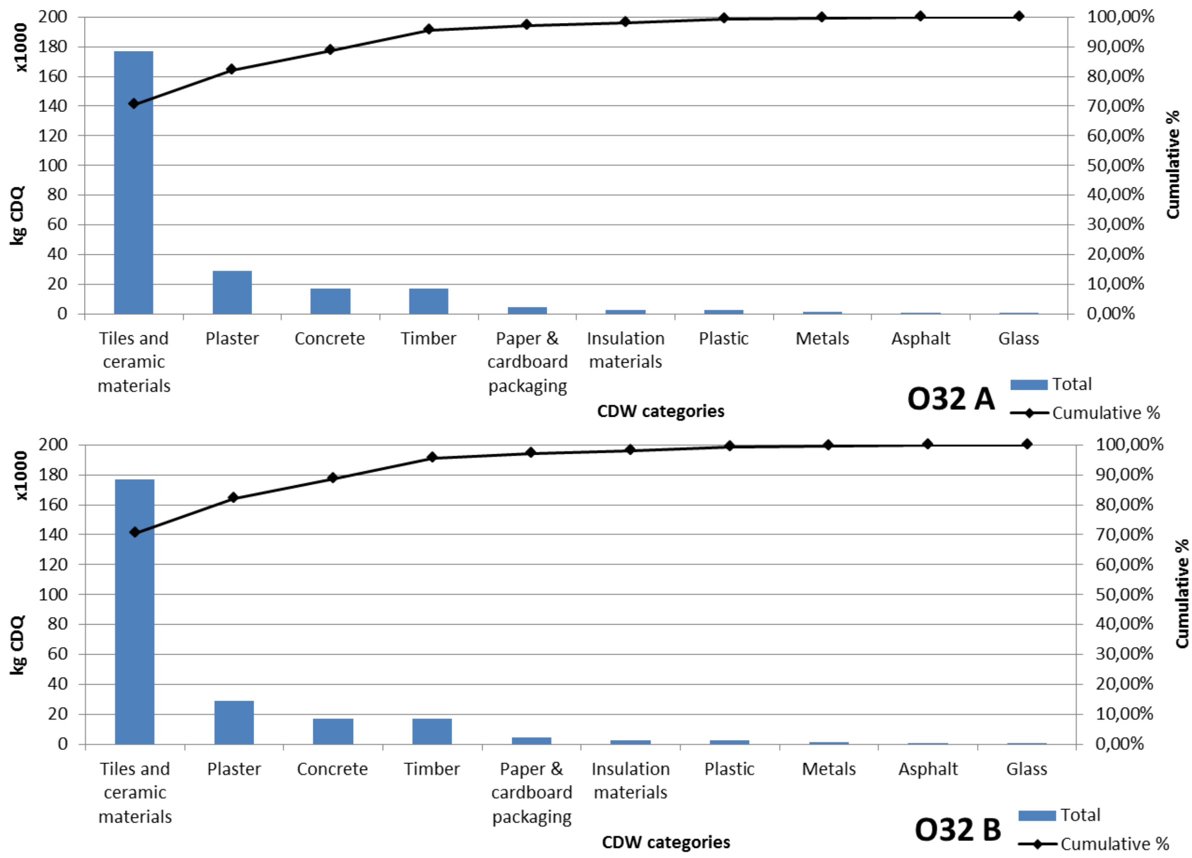


Fig 5. "Quantification of each CDW category generated during masonry and finishing works."

With the results obtained in fig. 5, a third indicator is determined to estimate the generation of each CDW category during the masonry and finishing works. This indicator relates the weight (kg) of each type of CDW generated during the masonry and finishing works, to the built surface (m^2) (table 7).

CDW category	O105	O32A - O32B	Mean i_3 (kg CDW/m^2built)
Tiles and ceramic materials	26,46	29,63	28,05
Plaster	4,79	4,86	4,83
Concrete	2,36	2,83	2,60
Paper & cardboard packaging	1,00	0,72	0,86
Timber	2,19	2,85	2,52
Metals	0,25	0,25	0,25
Plastic	0,32	0,42	0,37
Insulation materials	0,19	0,44	0,32
Asphalt	0,10	0,06	0,08
Glass	0,02	0,02	0,02

Tabla 7. "Relationship between quantities of each CDW category generated during the masonry and finishing works and the total built surface (i_3)."

No literature references have been found establishing indicators for each separate type of waste during the finishing and masonry works. Therefore, these results provide a first approximation.

6.- Conclusions

From all the above stated, we can conclude that the management models of CDW presently being used are not detailed enough to answer to the increasing social pressure and to make companies assume responsibilities in relation to environmental concerns. Following this concern, a detailed planning of CDW --prior to carrying out the construction-- using ratios or indicators, will help construction agents knowing, not only the quantity of waste generated, but also the moment when they will be generated enhancing the waste management strategies currently used today.

The ratios obtained in this research allows (once the total built surface is known) to estimate the CDW generation in a new building with similar characteristics to the projects analysed. Therefore, foreseeing these aspects in advance helps in assigning an optimal and systematic management of the waste produced, giving priority to treatments for reducing and reusing this waste as opposed to a definite disposal, as well as anticipating good practices for the correct management throughout the construction process.

In addition, a first approach to identify the activity generating more waste in a newly built residential project. Among the construction activities, it has been proved that masonry and finishing works are the ones generating more waste. In resume, the implementation of a specific management model in building works for these activities, which encourage the minimization and prevention of CDW at source, implementing best practices throughout the execution of the work, will lead to a proper management and minimization of about 70% of the total waste generated in newly built buildings, improving the environmental performance of the company.

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